TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 584

FLIGHT TESTS FOR THE DETERMINATION OF STATIC LONGITUDINAL STABILITY

By Hermann Blenk

From 1930 Yearbook
of the Deutschen Versuchsanstalt für Luftfahrt

Washington
September, 1930

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Introduction

The data obtained in flight measurements are generally inaccurate. In the attempt to compare the data of test flights with each other or wind tunnel data or calculations, it is usually found that the accuracy of the flight measurements is not great enough to draw indisputable conclusions. This explains why so many flight experiments which began on a large scale to reap a rich harvest, ended with so few results.

The inaccuracy can be traced, in part, back to the instruments used, while on the other hand, it rests on the impossibility of being able to actually maintain a certain flight position for a certain length of time. Even in very quiet weather, it is very difficult to maintain a constant altitude and static pressure together with the required accuracy. Whether much progress will be made in this respect, I am unable to state. According to my viewpoint it would require very sensitive instruments which would instantly indicate to the pilot even the slightest fluctuations of the airplane (as to height, static

*"Flugversuche zur Bestimmung der statischen Längsstabilität." From the 1930 Yearbook of the Deutschen Versuchsanstalt für Luftfahrt, pp. 49-53.

pressure, etc.).

Then, again, the accuracy differs according to the type of flight measurement. In general, it is possible to make more accurate measurements by constant altitude (for instance, speed measurements in straightaway flight) than during climbing or gliding. One might make flight tests which yield comparatively accurate data, but leave all others for the time being to model tests. Then, if the data of the flight tests agree with the corresponding wind-tunnel data, one can, with some caution look upon the remaining wind-tunnel data as correct, or, if there are discrepancies, make some corrections.

Another difficulty in flight-test measurements is the power plant. Wind-tunnel tests can be made without the engine, but no flight test. To obtain comparative values for the airplane structure alone, we would have to be able to eliminate the effect of the engine and propeller, respectively. This, however, is a difficult matter because the effect of the propeller on the airplane depends on the propeller as well as on the airplane itself. Decided progress is to be expected by the thrust and torque dynamometer hub,* although it could not be used for the present measurements, due to the lack of a dynamometer hub for this particular power plant.

*F. Seewald, "Über die Messung der Kräfte an Luftfahrzeugen." Zeitschrift für Flugtechnik und Motorluftschiffahrt, Vol. 19, 1928, p. 474.

The flight tests, reported here, are to furnish, at least for a small portion, a comparison with the model tests made in the Göttingen wind tunnel. They were made possible by the development of an accurate elevator setting recorder. This instrument was developed by the flight section of the D.V.L. (see 1929 Yearbook of the D.V.L., page 53) and subsequently, further improved (greater sensitiveness, straight guide for recording pin).*

N o t a t i o n

The following symbols were used:

G gross weight

F wing area

F_H area of horizontal tail group.

F_R area of elevator

F_S disk area of propeller.

b wing span.

t " chord.

t_H chord of horizontal tail group.

l_H distance of C.P. from horizontal tail group (1/3 of chord).

r backward position of C.P. with respect to leading edge of wing.

h low position of C.P. with respect to leading edge of wing.

S propeller thrust.

*Compare also : W. Hubner, "Stability and Stick Force Measurements on Junkers F.13ge." Report No. 166, 1929 Yearbook of the D.V.L.

v speed.

q static pressure.

q_H static pressure at horizontal tail group.

$\kappa = \frac{q_H}{q}$.

α angle of attack = angle of wind direction and wing chord.

β_H elevator setting, positive when upward (pulling).

c_n normal force coefficient for horizontal tail group.

Figure 1 is a sketch of Junkers A.35, which we used. A portion of the dimensions is likewise shown.

Test Installation

For shifting the C.P. position of the airplane, we installed a sliding weight, made of lead, as shown in Figure 2. In addition, we placed a tank in the rear of the fuselage, which, to make further backward shifting possible, could be filled with water. The tank had to be filled prior to take-off, but the lead weight could be shifted at will from the observer's seat. The tank was of the rip-bottom type so that the C.P. could be shifted forward when necessary (in forced landing, etc.). The elevator carried the above-mentioned setting recorder, which could be switched on or off from the observer's cockpit, where the indicator was installed. In addition, we carried a recording altimeter and a static pressure recorder on each flight.

Test Procedure

The tests were made with an ordinary Junkers (D 1010) A.35 type monoplane equipped with L 5 engine, (between December, 1928, and March, 1929), with Schollmeyer as pilot. The airplane was exactly weighed prior to each flight, for the same gross weight by the addition of fuel as required. The C.P. was determined in the usual manner by several weighings. The determination, made by various exactly known positions of the sliding weight and by empty and full water tank, gave a check on the C.P.

It was found during these tests that it sufficed to make these tests at the extreme positions of the sliding weight; that is, they were made by the following four C.P. positions:

1. Water tank empty, sliding weight forward;
2. " " " " " rear;
3. " " full, " " forward;
4. " " " " " rear.

First we made a series of speed flights (rectangular) as close to the ground as possible by various throttle settings, to calibrate the static pressure recorder.

The actual flight measurements were made either by constant throttle or constant static pressure. In this way we obtained a double check on the points of measurements and consequently, on the accuracy. In the flights with constant throt-

tle we successively changed the static pressures by different elevator settings, and kept in each position (about 1 minute) as carefully as possible. At the same time we recorded the static pressure and the elevator setting, once by sliding the weight forward, and a second time, with weight in back. Then we proceeded to the next static pressure. In the same manner we made a series of throttle positions by constant static pressure. Both types of flights were made with empty as well as filled water tank.

Figure 3 shows the faithful reproduction of a record of the elevator setting recorder and of the static pressure recorder. (It was impossible to photograph this record because the tracings of the silver pen on the paper were too fine, although they are visible to the eye.) In the various settings a denotes sliding weight forward, and b, in back.

Results of Tests and Comparison with Wind-Tunnel Data

The results of the C.P. determination are shown in Figure 4 and Table I, while Figure 5 gives the position of the individual weights in accordance with Table I.

Figure 6 represents the calibration curve of the elevator setting recorder. A 3.5° to 4° elevator setting corresponds to 10 mm. (.3937 in.).

TABLE I. Results of C.P. Determination

	Gross weight G in kg	Back position r in m	$\frac{r}{t}$	Load position h in m	$\frac{h}{t}$
Tank empty, sliding weight - front.	1502.5	0.802	0.3595	0.360	0.1615
Tank empty, sliding weight - back	1502.5	0.853	0.3824	0.354	0.1588
Tank full, sliding weight - front	1522.5	0.865	0.388	0.362	0.1623
Tank full, sliding weight - back	1522.5	0.915	0.410	0.356	0.1597

The rectangular flights for calibrating the static pressure recorder are shown in Figure 7. Since the paper strips of this recorder have no kg/m² scale, but km/h (as speed), we always give in place of the static pressure, the corresponding speed at 1000 meters (about 3280 feet) flying height (air density = 1.13 kg/m³ (.0705 lb./cu.ft.).

Figures 8-11 represent the entire data for the flight measurements, with angle of elevator setting β_H plotted against speed v. The graphs differ by the C.P. positions. The points of measurement for the same throttle position are connected by a curve. These points are spread considerably, but this is not due to any inaccuracy of the rudder setting recorder, but to the impossibility of being able to hold the rudder setting more than $\frac{1}{2}^{\circ}$ correct for $\frac{1}{2}$ minute. In subsequent measurements it undoubtedly will be of advantage to install some locking device which would also reduce the fluctuations in static pressure.

The more the C.P. is to the rear, the flatter the β_H

curves over v, for the slope of the curves is a measure for the static stability of the airplane.* Moreover, it is plainly seen that the throttle setting likewise has some effect on the slope of the curves, i.e., on the stability. By open throttle the curve is flatter than by idling; that is, the stability becomes less as the propeller r.p.m. increases, a fact well known in flying circles, although many books and reports state just the opposite. The reason for this discrepancy in theory and practice is due to the fact that until now the increase in static pressure on the tail due to the slipstream has been used in the calculation, but neglecting the downwash effect by the slipstream and the slipstream effect on the affected portion of the wing. But we can also prove theoretically that the longitudinal stability of an airplane is usually less at full throttle than when idling.

In order to obtain at least some figures from the multitude of points of measurements which can be compared with model measurements, we proceed as follows: Shifting the 31.5 kg (about 69 lb.) lead weight 240 cm (94.5 in.) from front to rear, denotes an added moment

$$M = 31.5 \times 2.40 = 75.6 \text{ mkg}$$

which, to assure constant static pressure and throttle setting,

*H. J. van der Maas, "Elevator Curves; Their Determination by Means of Flying Tests and Their Significance for the Judgment of the Stability." Rijks-Studiedienst voor de Luchtvaart, Amsterdam, Report V.325, 1929.
W. Hubner, "Determination of the Elevator Forces and the Longitudinal Stability of a Junkers F.13 ge Airplane." (Read a meeting of the W.G.L., Berlin, Nov., 1929. 1929 Yearbook of the W.G.L., Vol. V, p. 158-164.

must be compensated by a $\Delta \beta_H$ change in elevator setting.* So, with $q_H = \kappa q$ as static pressure on the horizontal tail surfaces, moment M must satisfy equation

$$M = \frac{\partial c_n}{\partial \beta_H} \Delta \beta_H q_H F_H l_H. \tag{1}$$

Thence, in our case (A.35: $F_H = 4.89$ m², $l_H = 4.75$ m) we have

$$c_n' \kappa = \frac{\partial c_n}{\partial \beta_H} \kappa = \frac{3.25}{q \Delta \beta_H} \tag{2}$$

This value is shown in Figures 12-16 plotted against the flight speed. The points of measurement appear to spread considerably. In averaging, we find that $c_n' \kappa$ must depend on the throttle setting; for throttle open, we save 0.0388, for throttle closed 0.0268.

According to the propeller theory κ becomes

$$\kappa = 1 + \frac{S}{q F_s} \tag{3}$$

where S = thrust, q = static pressure, and F_s = disk area of propeller. By the throttle settings, we measured the maximum airplane speed in level flight for

Open throttle,	200 km/h
Throttle setting 1,	175 "
" " 2,	150 "
" " 3,	110 "

*Strictly speaking, the c_m value of the wing changes also, because, changing $\Delta \beta_H$ by constant throttle and constant static pressure, does produce some change in the c_a value of the wing, although the effect is practically negligible.

Now, with the polar of the model test as basis, we can compute the required thrust for level flight for each throttle setting. Moreover, with

$$S = S_o - \sigma \, q \, F_s \tag{4}$$

as formula for the dependency of the propeller thrust on the static pressure, and the estimated thrust at S_o setting based on the observed r.p.m. and corresponding propeller torque measurements, all quantities for defining κ are given. Consequently, for

Open throttle	$S = 450 - 0.1350 \, q \, F_s$,
Throttle setting 1:	$S = 310 - 0.0991 \, q \, F_s$,
" " 2:	$S = 215 - 0.0755 \, q \, F_s$,
" " 3:	$S = 170 - 0.0635 \, q \, F_s$.

Hence, for

$$\left.\begin{array}{ll} \text{Open throttle} & \kappa = 0.8650 + \dfrac{63.7}{q} \\ \text{Throttle setting 1:} & \kappa = 0.9009 + \dfrac{43.9}{q} \\ \text{" \quad " \quad 2:} & \kappa = 0.9245 + \dfrac{30.2}{q} \\ \text{" \quad " \quad 3:} & \kappa = 0.9365 + \dfrac{24.0}{q} \end{array}\right\} \tag{5}$$

Dividing the above $c_n' \, \kappa$ of Figures 12-16 by the corresponding κ values, we obtain κ. In Figures 12-16, we see that the spread of the c_n' values over v is not much less than that of the $\kappa \, c_n'$ values. But now the mean c_n' check very satisfactorily for the individual throttle settings. We have for

Open throttle	$c_n' = 0.0293$	(25 points of measurement)
Throttle setting 1:	$c_n' = 0.0286$	(13 "
" " 2:	$c_n' = 0.0312$	(13 "
" " 3:	$c_n' = 0.0310$	(14 "

The total average is $c_n' = 0.0299$. The model measurements on the A.35 show $c_n' = 0.0294$. The curves $c_n' \kappa = 0.0299$ (according to formula 5) are plotted against v in Figures 12-15.

The flight test by idling yielded $\kappa\ c_n' = 0.0268$; hence, we conclude that $\kappa = \frac{0.0268}{0.0299} = 0.896$, or, in other words, the blanketing effect of the propeller, while idling, and the effect of the fuselage is such that the static-pressure on the horizontal tail surfaces of the A.35, when idling, is only about 90% of the static pressure in flight.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

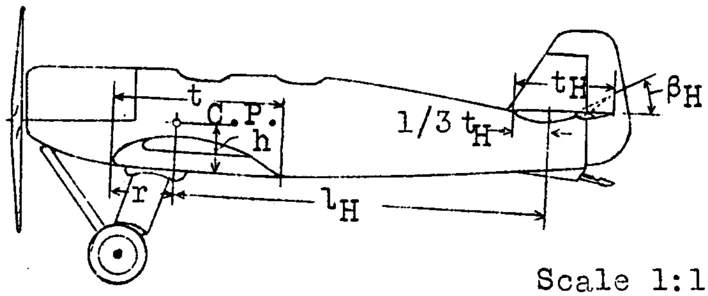


Fig.1 Side view of Junkers A 35.

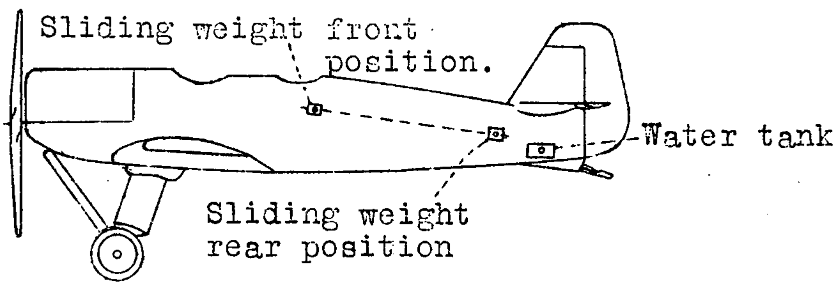


Fig.2 Sliding weight and water tank position (scale 1:100).

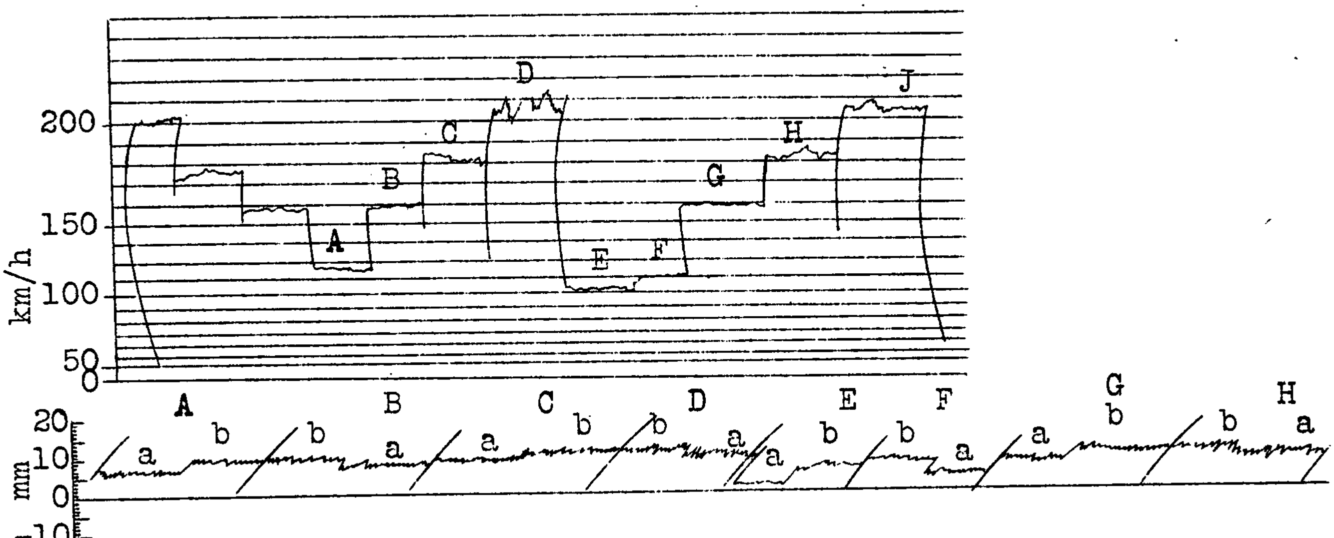
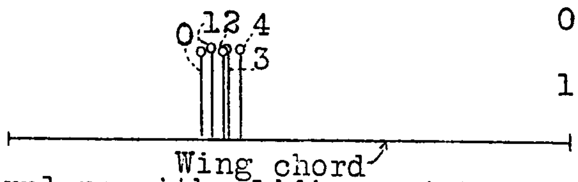


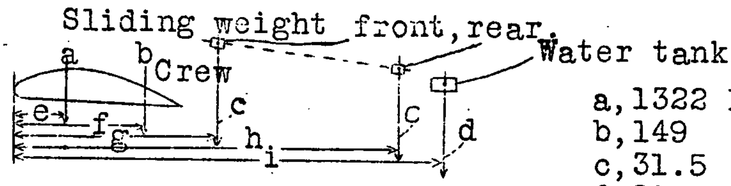
Fig.3 Record of elevator setting recorder, and of static pressure recorder (1/2 natural size.)



C.P.positions
0, Airplane minus additional weights.
1, Airplane with sliding weight front and tank empty.
2, Airplane with sliding weight rear and tank empty.
3, " " " " front " " full.
4, " " " " rear " " ".

Fig.4 C.P. positions (scale 1:30)

Airplane without crew and additional weights.



a, 1322 kg.
b, 149 "
c, 31.5 "
d, 20 "
e, 658
f, 1685
g, 2660
h, 5060
i, 5660

Fig.5 Weights with respect to wing(scale 1:100)

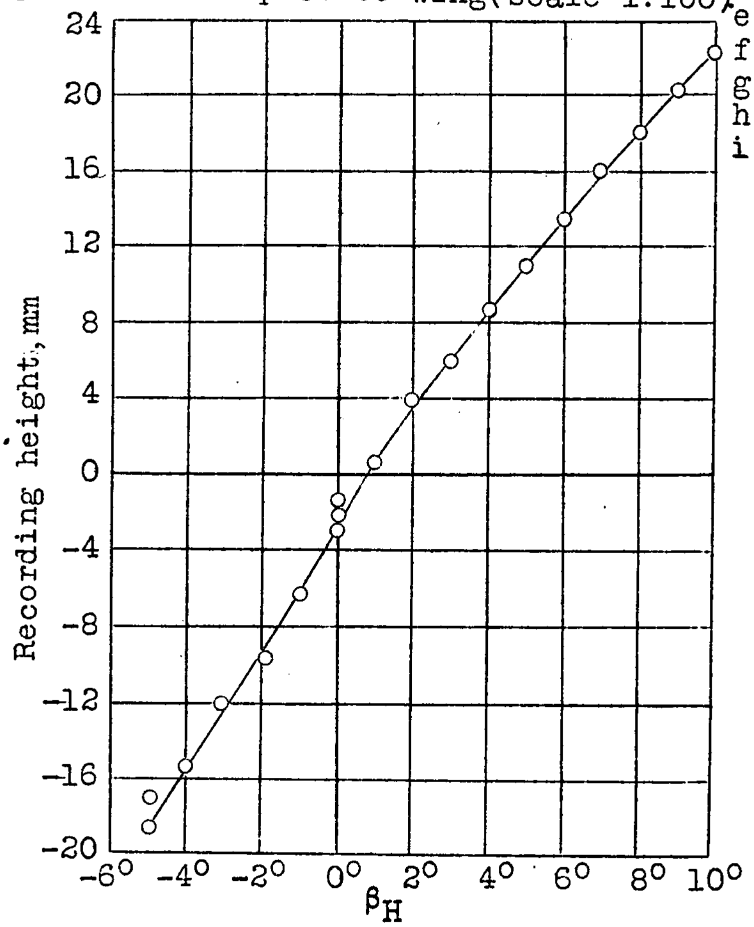


Fig.6 Calibration curve of elevator setting recorder.

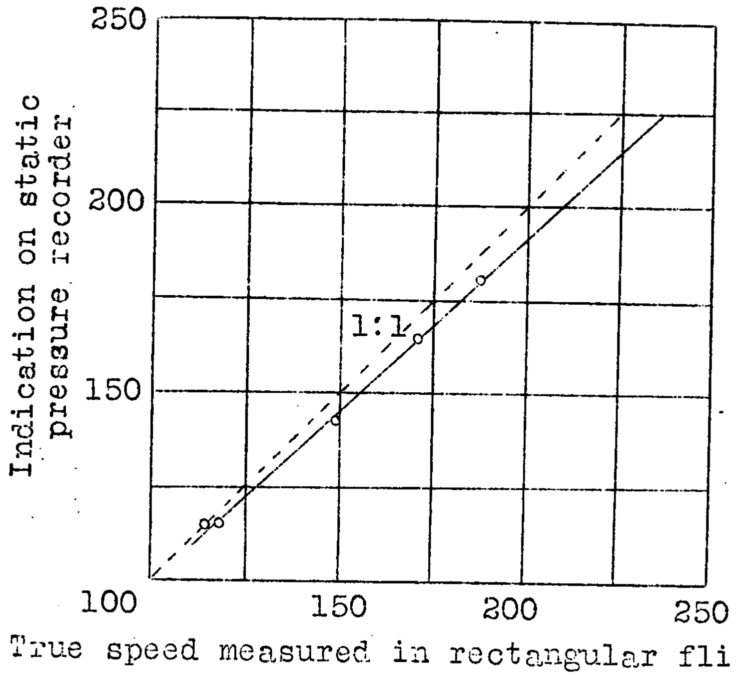


Fig.7 Calibration curve static pressure.

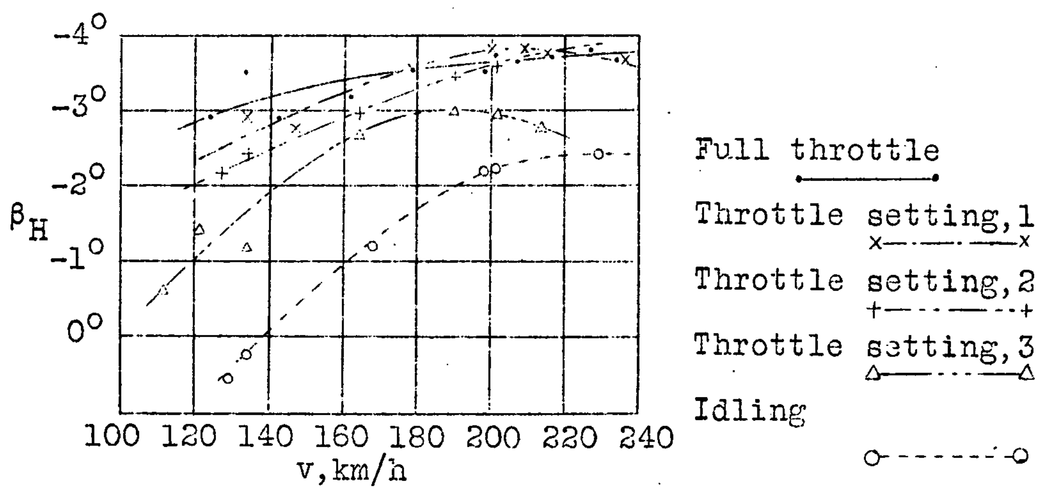


Fig.8 Test data in steady flight with foremost C.P. position(tank empty sliding weight front.)

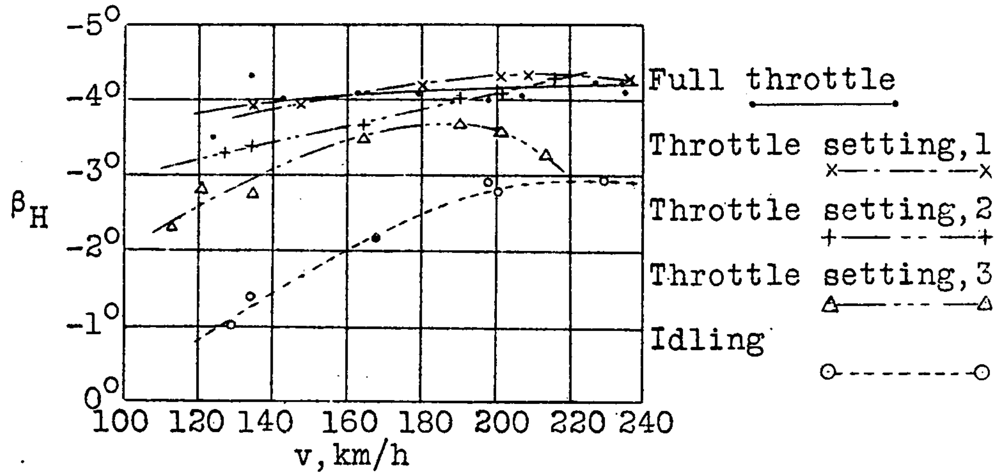


Fig.9 Test data in steady flight with C.P.position 2,(tank empty,sliding weight back.)

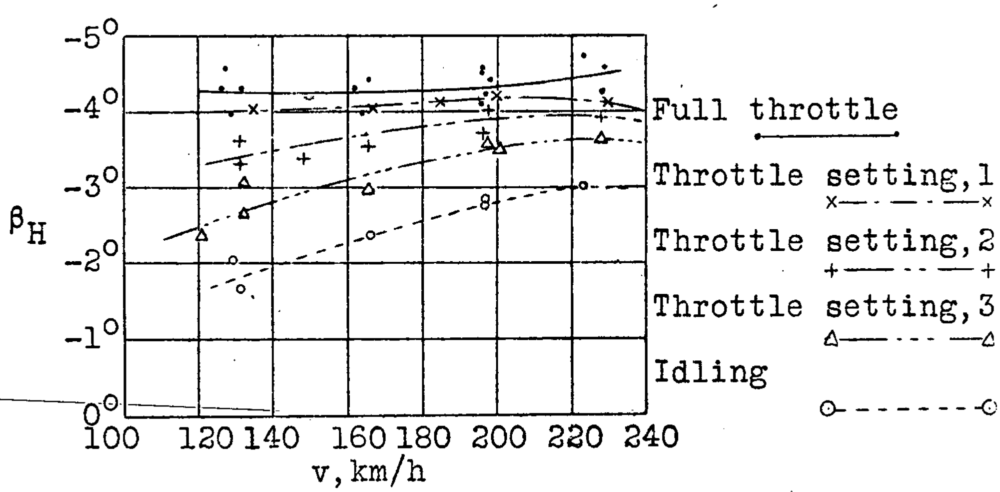


Fig.10 Test data in steady flight with C.P.position 3,(tank full,sliding weight forward.)

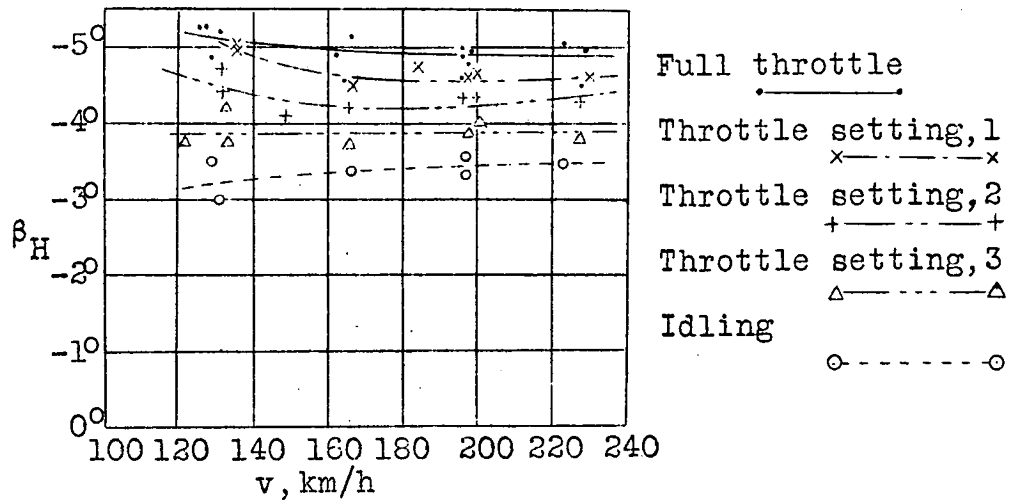


Fig.11 Test data in steady flight, C.P. position far back, (tank full, sliding weight back.)

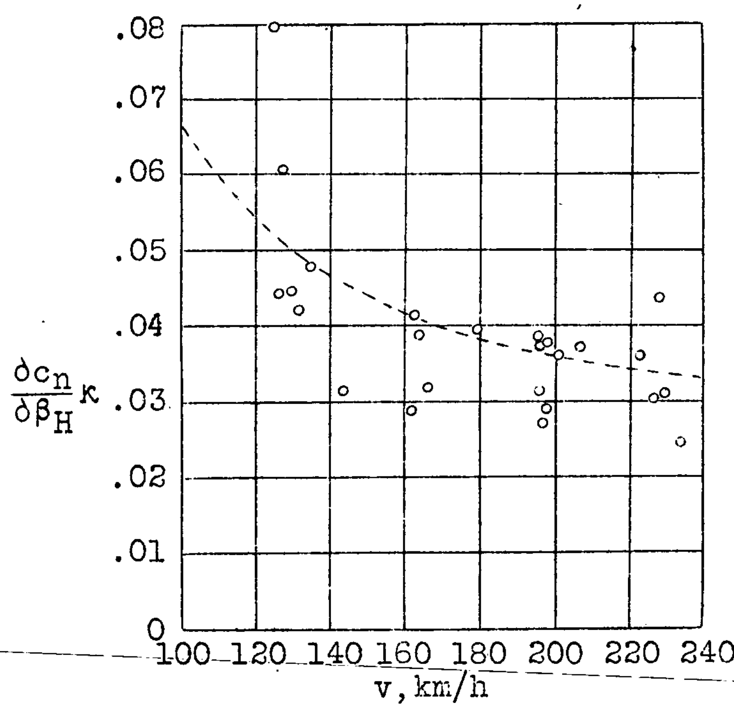


Fig.12 Computation of total test data for full throttle.

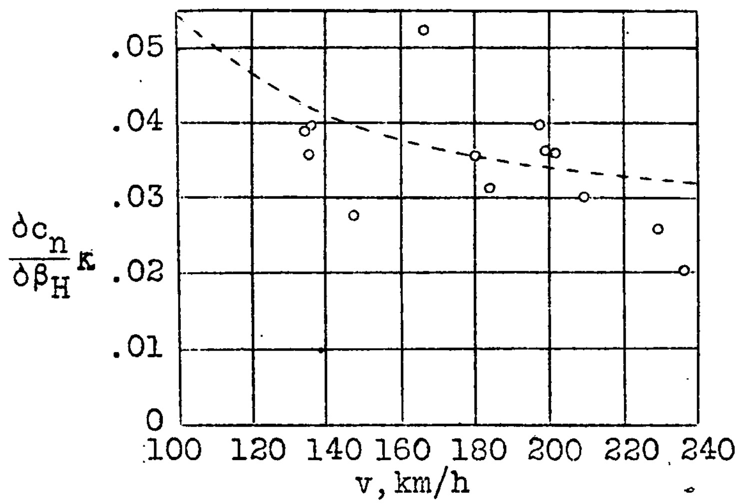


Fig.13 Computation of total test data for throttle setting, 1.

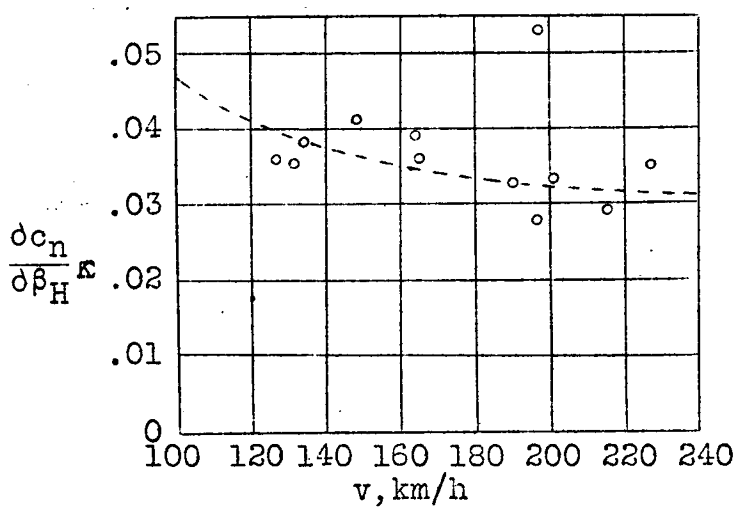


Fig.14 Computation of total test data for throttle setting, 2.

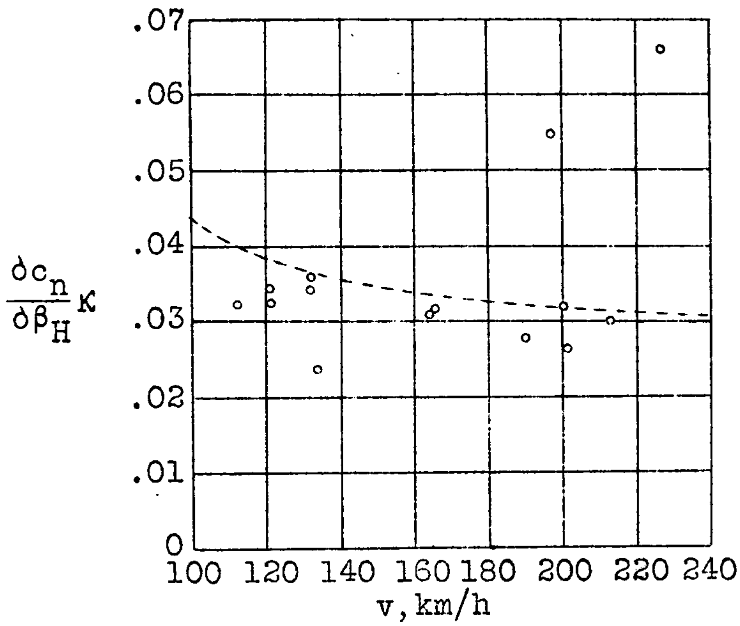


Fig.15 Computation of total test data for throttle setting 3.

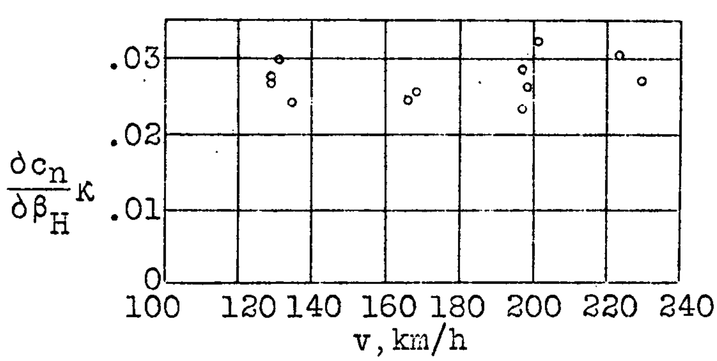


Fig.16 Computation of total test data for idling.